# Dynamic Autonomy for Mobile Manipulation


David Bruemmer, Douglas Few, Robert Kinoshita

*Robotic and Human Systems Group*
*Idaho National Laboratory*
*Idaho Falls, ID, U.S.A.*
*{david.bruemmer,douglas.few, robert.kinoshita}@inl.gov*

Chetan Kapoor

*Robotics Research Group*
*University of Texas at Austin*
*Austin, TX, U.S.A*
*chetan@mail.utexas.edu*

Mike Goza

*Johnson Space Center*
*NASA*
*Houston, TX, U.S.A.*
*s.m.goza@nasa.gov*



***Abstract*** *– Emergency response demands a very different kind of robotic solution than those created for known environments (e.g. factory robots) and well understood tasks (e.g. power plant maintenance). This paper discusses efforts undertaken by the Idaho National Laboratory (INL) to develop highly mobile, highly dexterous robots that can function autonomously or semi-autonomously as a human surrogate in critical emergency situations. This paper reports progress made on two projects pursued under the auspices of the INL mobile manipulation initiative. The first involves collaboration with NASA Johnson Space Center (JSC) to merge an autonomous mobile robot base running the INL Intelligence Kernel, a behavior based robot control architecture, with the NASA Robonaut torso. The Robonaut torso was originally developed for use on the International Space Station, but also has strong potential to be used across a variety of national security, homeland defense, energy and search and rescue applications. The second capability pursued under the INL mobile manipulation initiative involves merging autonomous reaching and grasping behaviors developed at the University of Texas with the INL Intelligence Kernel to carry out tasks such as autonomously opening doors and retrieving objects within cluttered indoor settings. The ability of these systems to exploit environments and tools designed for humans allow them to be used in emergency situations where there is no time to develop a niche-specific robot, such as time critical threats involving Chemical/Biological/Radiological Nuclear (CBRN) hazards.*


## I. INTRODUCTION

Mobile manipulation offers a compelling opportunity to meld human intelligence with robotic proficiency, but at the same time, the many degrees of freedom present new challenges. The robots currently used in critical and hazardous environments including military, energy, industry and homeland defense contexts require a teleoperator to control these many degrees of freedom. This teleoperated approach requires significant training and is subject to all of the communication challenges associated with continuous master-slave control. To address these challenges, the Mobile Manipulation initiative at the INL is developing flexible autonomy that can support changing levels of operator involvement (i.e., teleoperation, shared control, autonomy), and also changing areas of operator focus (i.e., driving, grasping, reaching, visual servoing, etc.). To support these levels of control, research is necessary to combine simultaneous mapping and localization, obstacle avoidance, path planning, and waypoint behaviors with the physical dexterity, visual perception and autonomous manipulation capabilities necessary to open doors, assemble simple structures and use tools designed for human hands.

Through the Joint Robotics Program (JRP) Technology Transfer Program, the INL is working with the Naval Space and Warfare Center in San Diego, which has provided an all-terrain robot platform to be used as the basis for developing mobile manipulation capabilities. The mobile manipulation initiative also includes Brigham Young University, which is working to develop novel graphical interfaces for tasking intelligent mobile manipulation systems. Also, under this collaborative endeavor, the University of Texas has worked to marry the current INL Robot Intelligence Kernel with the Operational Software Components for Advanced Robotics (OSCAR) -- an object-oriented framework for the development of generic manipulator control algorithms.[1] The goal of this effort is to make mobile manipulation capabilities viable for near-term use in critical, hazardous environments.

Already the Robot Intelligence Kernel is being ported onto the PackBot and Talon robots towards the goal of near-term deployment in theater. For a variety of explosive ordinance disposal (EOD) and improvised explosive device (IED) defeat applications, these robots can benefit from autonomous reaching and grasping capabilities as well as other manipulation capabilities that can be derived from the OSCAR framework. Currently, the EOD Packbot and other robots that have manipulation

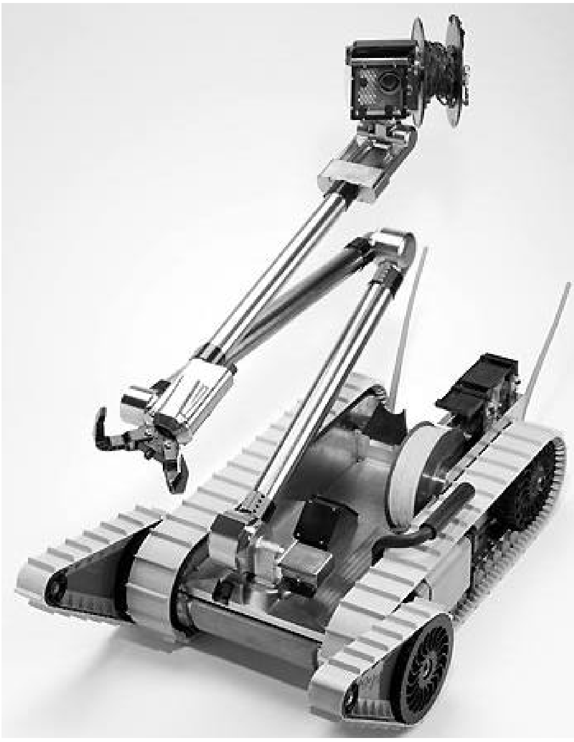

Fig. 1: The iRobot Explosive Ordinance Disposal (EOD) robot U.S. Army

capabilities require operators to have extensive training and to devote significant workload to the manipulation as well as navigation aspects of the task. By using intelligent navigation and manipulation behaviors as part of a dynamic autonomy architecture, it may be possible to reduce training and workload demands on the operator.

Another area where mobile manipulation capabilities may be utilized is space and planetary exploration. Under the mobile manipulation initiative, the INL has been working to develop a suite of capabilities that can be used to facilitate the near-term use of the Robonaut system developed by the NASA Johnson Space Center [2,3]. Efforts are underway to adapt the capabilities of the INL Robot Intelligence Kernel to provide intelligent mobility to the humanoid torso.

NASA JSC has developed autonomous behaviors for visual perception, reaching, grasping and handling. The INL has developed robust, reliable mobility behaviors, decision-making, and self-status assessment on board the robot platform. The mobile manipulation initiative is intended to marry these capabilities into a single behavior architecture and apply it to real-world tasks in unstructured environments. Although the primary objective of this effort is space and planetary exploration, the hope is that the resulting capabilities will be equally valuable for a spectrum of defense, energy and industrial applications. One of the challenges to be faced for this particular application of mobile manipulation technologies is that the cost for the humanoid torso is relatively high at the present time. However, for applications such as nuclear power plants as well as high-criticality defense related missions such as counter-terrorism operations, the ability to employ a human surrogate that can use a wide variety of human tools is worth the cost.

Fig. 2: INL will provide the platform mobility for NASA’s Robonaut -- a highly dexterous robot designed for use on the Space Station.

## II. APPLICATION 1: RECONFIGURABLE MOBILE MANIPULATION FOR URBAN RECONNAISSANCE

### II.A. Purpose

The purpose of this effort is to extend the scope and functionality of the INL Robot Intelligence Kernel from an architecture focused on intelligent platform mobility to one that encompasses a variety of platform independent, reconfigurable manipulation capabilities including scanning arms for countermine operations to modular manipulators for specialized maintenance applications. The goal is to grow the suite of autonomous behaviors and tasking tools that are included in the Robot Intelligence Kernel, extending from information gathering to functionality that can meaningfully affect the environment around the robot. With this goal in mind, technical efforts have begun to tackle basic tasks including autonomously opening doors and retrieving objects within cluttered environments.

### II.B Implementation

The first step of this collaborative effort was to interface a modular robot arm and gripper to the iRobot ATRV provided by the JRP Technology Transfer Program. The University of Texas, Austin worked to provide the hardware mounting, electronic and power interface as well as the software application program interface (API) for the modular arm. This API is based on the OSCAR framework developed by UTA over the past decade. Like the INL Robot Intelligence Kernel, the object oriented nature of the OSCAR framework provides platform independence and has enabled OSCAR to be used with many different manipulator systems. In addition, the OSCAR framework provides reconfigurability and performance-based decision making across a variety of control algorithms. [4,5] Working with the INL, the UTA team has completed the implementation of a manipulation software class within the Intelligence Kernel software that allows the INL Intelligence Kernel to have access to the OSCAR framework. The INL Intelligence Kernel can now be used to exchange data with and control a large number of arms and grippers already defined within the OSCAR framework.

Fig. 3: The JRP Tech Transfer Robot with 4 DOF arm and gripper

A frame has been designed and mounted on the ATRV platform. This frame now supports additional batteries, a suite of sensors such as iGPS (indoor positioning system), force-torque, and a modular manipulator that can be assembled in custom configurations to meet specific application needs. This modular manipulator has been mounted and used in several different configurations including a four- and six-degree-of-freedom (DOF) version.

These degrees of freedom, coupled with the navigation task, require a new approach to human-machine interaction. The mobile manipulation initiative is funding the development of a 3-D interface that will allow the user to visualize the robot and its manipulator as it moves through an abstracted representation of the environment. This “augmented virtuality” display is constructed on-the-fly from real (i.e. video) and virtual (i.e. SLAM map, semantic icons) elements. This display has been shown to reduce operator workload and error while increasing overall task efficiency for search, exploration and mapping tasks when compared to a standard teleoperation interface [6,7]. This interface is now being modified to include user support tools and visualization modules dedicated to manipulation capabilities.

II.C Results

Currently, the system is operational with the iGPS, a 6-DOF manipulator with full coordinated control implemented using the OSCAR software framework, a force-torque sensor mounted at the robot end-effector for object manipulation. In addition to the above, OSCAR code had been integrated with the INL Intelligence Kernel which provides intelligent mobility capabilities including obstacle avoidance, waypoint navigation, path planning, mapping, and localization [8]. With these capabilities, it is now possible to accomplish several complex indoor reconnaissance tasks.

Using the resulting system, the UT research team has demonstrated the ability of the robot to traverse a cluttered indoor environment in order to locate, pick up and stow an object of interest within a room. Also, the research team has successfully demonstrated the ability of the mobile manipulation unit to autonomously navigate through a cluttered indoor building and open a door. This requires the robot to find the door, approach the door, grab the door handle, turn the handle and open the door. Researchers at UT are using an experimental environment that consists of a door frame that can be adjusted to offer varying force interaction between the manipulator and the door. Based on this setup, the all-terrain robot can now intelligently maneuver to the door using the INL Intelligence Kernel mobility software, use the manipulator to grab the door knob, twist it, and partially open the door. The next step is to fully open the door and have the mobile manipulation system go through the door. This is a highly complex and demanding task since it involves the fine coordination between the platform and the manipulator as well as reasoning about the spatial relationship of several dynamic entities including the door, the robot, the arm and the gripper.

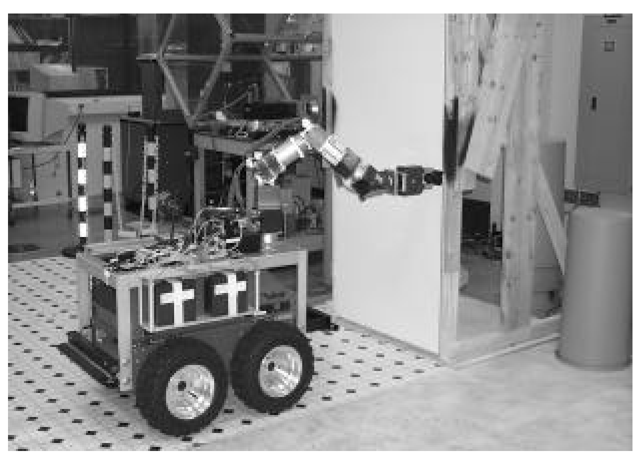

Fig. 4: The JRP Tech Transfer robot opens doors with a 6 DOF arm and gripper.

## III. APPLICATION 2: DYNAMIC AUTONOMY FOR SPACE AND PLANETARY EXPLORATION

### III.A Purpose

NASA JSC has been working for several years with other universities including Vanderbilt, Massachusetts Institute of Technology and University of Massachusetts to develop perceptual capabilities and reaching and autonomous grasping behaviors. However, in order to function as a human surrogate, the overall system must be able to do more than vision-based dexterous behaviors. To accomplish a variety of real-world tasks in unstructured environments, it will be necessary to marry simultaneous mapping and localization, obstacle avoidance, path planning, and waypoint behaviors with the physical dexterity, visual perception and autonomous manipulation capabilities necessary to open doors, assemble simple structures and use tools designed for human hands. The goal of this effort is not to provide full autonomy, but rather to promote dynamic autonomy such that the navigation and manipulation behaviors on board the robot can support whatever level of intervention is handed down from the user.

### III.B Implementation

NASA JSC has provided the INL with the necessary software protocol to interface to the Robonaut system via a CANbus interface. Also, under the JRP Technology Transfer Program, the Space and Naval Warfare Systems Center in San Diego has already provided a specially modified Segway Robot Mobility Platform (RMP) to be used as the base platform for the Robonaut torso [9].

Fig. 6: NASA JSC Mobile Robonaut

The INL Robot Intelligence Kernel has been adapted to the Segway Robotic Mobility Platform (RMP) and modified to include a new 360 degree scanning laser that provides the range information needed for obstacle avoidance and simultaneous localization and mapping. The Segway RMP has also been outfitted with a long range radio to communicate with the Intelligence Kernel OCU as well as wireless Ethernet and a small computer. The Robot Intelligence Kernel is now fully functional on the Robotic Segway Platform. Through these efforts, the Robonaut system can inherit the entire suite of capabilities now included with the Intelligence Kernel including obstacle avoidance, mapping and localization, path planning, laser and visual tracking, human presence detection and real-time occupancy-grid change detection.

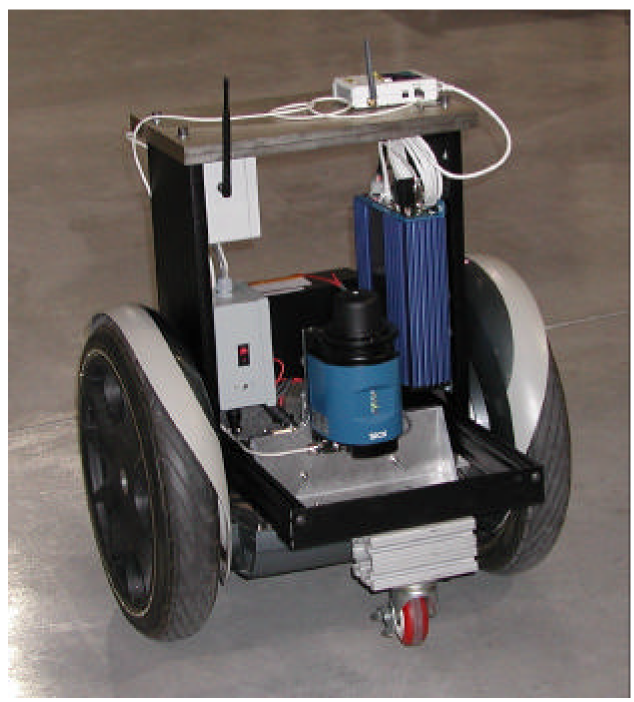

Fig. 5: The Segway RMP

### III.C. Results

Due to the many degrees of freedom present on the humanoid torso, much of the work in this effort has centered on the development of dynamic autonomy that can support varying levels of operator intervention. Currently, the following four modes of control have been developed for the mobile Robonaut system:

1. “Safe” Manual Mode is a fully manual mode of operation, in which the operator must manually control all robot movement including the arm and mobility platform. However, the Safe Mode capabilities mean that the robot is equipped with a level of initiative to prevent the operator from colliding with obstacles.

2. Mixed Mode means that the human can select to have the robot mobility be autonomous while the arm is still subject to manual control.

3. In Shared Mode, the robot relieves the operator from the burden of direct control of either the arm or autonomous mobility. This mode exploits the reactive behaviors to provide robust navigation and autonomous reaching and grasping based on the robot’s perception of the local environment.

4. Autonomous Mode consists of high-level tasking whereby the robot manages all decision-making and navigation.

Each of these modes will support differing levels of operator trust, operator training and expertise, and cognitive workload as well as the availability of communication bandwidth. Currently, the architecture exists to support these varying levels of autonomy, but much work remains to empirically evaluate and hone these levels of control as they are used to accomplish real-world missions.

## IV. CONCLUSIONS

Through collaboration between several institutions including BYU, UT, SPAWAR, and NASA JSC, the mobile manipulation initiative provides the robotics community with an extensible, common framework for intelligent mobile manipulation. This effort has combined many years of intelligent manipulation and navigation research funded over the past decade by the Department of Defense and Department of Energy into a single, useful architecture. This architecture can be ported and reconfigured to provide dynamic autonomy for a variety of different mobile robots and for a variety of manipulators. The ability of the resulting system to autonomously accomplish basic tasks such as autonomously opening doors and retrieving objects from cluttered rooms indicates that the goals of mobile manipulation are within reach. The resulting architecture already provides turn-key mobile manipulation capabilities that can directly impact the utility of small mobile robots used across a variety of tasks and environments. Future work will focus on providing experimental evidence to metric the limitations and advantages of autonomy when compared against teleoperated strategies. Also, further work will create a high-utility, flexible human-machine interface, allowing human operators to infuse intelligence and insight into the functioning of mobile manipulation systems that are more complex and more capable than any robotic systems we have yet seen.

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